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A review on biodiesel production, combustion, emissions and performance

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ABSTRACT

This article is a literature review on biodiesel production, combustion, performance and emissions. This study is based on the reports of about 130 scientists who published their results between 1980 and 2008. As the fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best available sources to fulfill the energy demand of the world. More than 350 oil-bearing crops identified, among which some only considered as potential alternative fuels for diesel engines. The scientists and researchers conducted tests by using different oils and their blends with diesel.

A vast majority of the scientists reported that short-term engine tests using vegetable oils as fuels were very promising but the long-term test results showed higher carbon built up and lubricating oil contamination resulting in engine failure. They concluded that vegetable oils, either chemically altered or blended with diesel to prevent the engine failure. It was reported that the combustion characteristics of biodiesel are similar as diesel and blends were found shorter ignition delay, higher ignition temperature, higher ignition pressure and peak heat release. The engine power output was found to be equivalent to that of diesel fuel. In addition, it observed that the base catalysts are more effective than acid catalysts and enzymes.

Contents

1. Introduction

As the fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best available sources to fulfill the energy demand of the world. The petroleum fuels play a very important role in the development of industrial growth, transportation, agricultural sector and to meet many other basic human needs. However, these fuels are limited and depleting day by day as the consumption is increasing very rapidly. Moreover, their use is alarming the environmental problems to society. Hence, the scientists are looking for alternative fuels. India is importing more than 80% of its fuel demand and spending a huge amount of foreign currency on fuel. Biodiesel is gaining more and more importance as an attractive fuel due to the depleting nature of fossil fuel resources. The purpose of transesterification process is to lower the viscosity of the oil. The main drawback of vegetable oil is their high viscosity and low volatility, which causes poor combustion in diesel engines. The transesterification is the process of removing the glycerides and combining oil esters of vegetable oil with alcohol. This process reduces the viscosity to a value comparable to that of diesel and hence improves combustion. Biodiesel emits fewer pollutants over the whole range of air–fuel ratio when compared to diesel. Biodiesel can produce by using different

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techniques such as ultrasonic cavitation, hydrodynamic cavitation, microwave irradiation, response surface technology, two-step reaction process etc. Experiments had been conducted for different types of combustion chambers. It was found that spherical combustion chamber gives better results than other type of combustion chambers. The scientists tested a number of different raw and processed vegetable oils like rapeseed oil, sunflower oil, palm oil, soybean oil. In this paper, the results of some of the researchers has compared and summarized.

2. Production of biodiesel

Researchers and scientists had developed different methods for biodiesel production from different bio fuels. A brief review of these methods has presented here. Most of the researchers/scientists reported that the production of biodiesel was more when the process was used a catalyst.

Ahn et al. [1] followed a two-step reaction process to produce biodiesel. Using this method canola methyl ester (CME), rapeseed methyl ester (RME), linseed methyl ester (LME), beef tallow ester (BTE) and sunflower methyl ester (SME), synthesized in a batch reactor using sodium hydroxide, potassium hydroxide and sodium methoxide as catalysts. Cvengro and Povaz [2] described biodiesel production by using two-stage low-temperature transesterification of cold pressed rapeseed oil with methanol at temperatures up to 70 °C. A new enzymatic method of synthesizing methyl esters from plant oil and methanol in a solvent-free reaction system was developed by Masaru et al. [3]. In the same year, Uosukainen et al. [4] presented statistical and experimental design to evaluate interdependence of process variables in enzymatic transesterification. The authors also studied the alcoholysis of rapeseed oil methyl ester (biodiesel). Fangrui and Hanna [5] had reviewed the biodiesel production. Samukawa et al. [6] investigated the effects of the pretreatment of immobilized *Candida antarctica* lipase enzyme (Novozym 435) on methanolysis for biodiesel fuel production from soybean. Ikwuagwu et al. [7] discussed the production of biodiesel using rubber seed oil. The effect of three principal variables namely molar ratio of methanol to oil, amount of catalyst and reaction temperature on the yield of acid-catalyzed production of methyl ester (biodiesel) from crude palm oil had been studied by Crabbe et al. [8].

Transesterification reaction of rapeseed oil in supercritical methanol was investigated without using any catalyst by Saka and Kusdiana [9]. Yuji Shimada et al. [10] studied the enzymatic alcoholysis for biodiesel fuel production. Pizarro and Park [11] studied the production of biodiesel fuel from vegetable oils contained in waste activated bleaching earth. Shieh et al. [12] optimized the biodiesel production from soybean by using response surface technology. Zhang et al. [13] reported that the acid-catalyzed process using waste cooking oil has proved to be technically feasible with less complexity than the alkali-catalyzed process using waste cooking oil. Fatty acid methyl ester (FAME) production from waste activated bleaching earth discarded by the crude oil refining industry was investigated by Kojima et al. [14] using fossil fuel as a solvent in the esterification of triglycerides.

Kusdiana and Saka [15] discussed the effects of water on biodiesel fuel production by supercritical methanol treatment. Tashtoush et al. [16] conducted an experimental study on evaluation and optimization of conversion of waste animal fat into biodiesel. Ghadge and Raheman [17] studied biodiesel production from mahua (*Madhuca indica*) oil having high free fatty acids. Van Gerpen [18] discussed the effects of reaction time, reaction temperature on quality and quantity of esters. It is concluded that a trade-off between reaction time and temperature as reaction completeness is the most critical fuel quality parameter [18]. Xu et al. [19] proposed a simplified model to describe the reaction kinetics of the biodiesel production. Cao et al. [20] had carried out transesterification of soybean oil in supercritical methanol in the absence of catalyst.

Ramadhas et al. [21] studied biodiesel production from high free fatty acid rubber seed oil. They developed a two-step transesterification process to convert the high free fatty acid oils to its mono-esters. The major factors affect the conversion efficiency of the process such as molar ratio, amount of catalyst, reaction temperature and reaction duration analyzed [21]. Karmee and Chadha [22] prepared biodiesel from the *Pongamia pinnata* by transesterification in the presence of potassium hydroxide as catalyst. Ghadge and Raheman [23] discussed the preparation of biodiesel from high free fatty acid oils by using response surface methodology. In the same year, Canoira et al. [24] presented a process to convert the Jojoba oil wax to biodiesel by transesterification with methanol.

Waste frying oils transesterification was studied by Felizardo et al. [25] with the purpose of achieving the best conditions for biodiesel production. In the same year, Miao and Wu [26] introduced an integrated method for the production of biodiesel from microalgal oil. Zhu et al. [27] produced biodiesel from jatropha curcas oil using a heterogeneous solid super base catalyst (calcium oxide). Meher et al. [28] reviewed the technical aspects of biodiesel production by transesterification. Al-Zuhair et al. [29] discussed the effect of fatty acid concentration and water content on the production of biodiesel. Xue et al. [30] had developed a new method for preparing raw material for biodiesel. Production of fatty acid methyl esters from crude tobacco seed oil (TSO) having high free fatty acids (FFA) was investigated by Veljković et al. [31]. Royon et al. [32] studied the enzymatic production of biodiesel by methanolysis of cottonseed oil. A two-phase membrane reactor had developed to produce biodiesel from canola oil by Dubé et al. [33].

Li et al. [34] optimized the whole cell-catalyzed methanolysis of soybean oil for biodiesel production using response surface methodology. Transesterification reaction of used frying oil by means of ethanol, using sodium hydroxide, potassium hydroxide, sodium methoxide, and potassium methoxide as catalysts, was studied by Encinar et al. [35]. Issariyakul et al. [36] studied the production of biodiesel from waste fryer grease using mixed methanol/ethanol system. Chisti [37] discussed the biodiesel production from microalgae. A packed-bed reactor (PBR) system using fungus whole-cell biocatalyst has developed for biodiesel fuel production by plant oil methanolysis by Hama et al. [38]. Fatty acids methyl esters had prepared by Hernando et al. [39] under microwave irradiation, using homogeneous catalysis, either in batch or in a flow system. They reported that the process using microwaves irradiation proved to be a faster method for alcoholysis of triglycerides with methanol, leading to high yields of fatty acid methyl ester [39].

Exergy Flow Analysis (ExFA) is applied to the process of biodiesel production by Talens et al. [40]. Production of fatty acid methyl ester from palm fatty acid distillate (PFAD) having high free fatty acids was investigated by Chongkhong et al. [41]. Response surface methodology (RSM) based on central composite rotatable design (CCRD) was used to optimize the three important reaction variables namely methanol quantity, acid concentration and reaction time for reduction of free fatty acid content of the oil to around 1% by Tiwari et al. [42]. Rathore and Giridhar [43] investigated synthesis of biodiesel from edible oils like palm oil and groundnut oil and from crude non-edible oils like *Pongamia pinnata* and *Jatropha curcas* in supercritical methanol and ethanol without using any catalyst from 200 °C to 400 °C at 200 bar. Demirbas [44] studied a non-catalytic biodiesel production with supercritical methanol, which allows a simple process and high

yield because of the simultaneous transesterification of triglycerides and methyl esterification of fatty acids. Non-catalytic biodiesel production technologies from oils/fats in plants and animals developed by Imahara et al. [45] employing supercritical methanol.

3. Combustion of biodiesel

The different combustion characteristics such as ignition delay, ignition temperature, and spray penetration of different biodiesel fuels had reviewed in a detailed manner in the subsequent paragraphs.

Zhang and Van Gerpen [46] investigated the use of blends of methyl esters of soybean oil and diesel in a turbo-charged, four-cylinder, direct injection diesel engine modified with bowl in piston and medium swirl type. They found that the blends gave a shorter ignition delay and similar combustion characteristics as diesel [46]. Radwan et al. [47] investigated the effect of ignition delay period of jojoba methyl ester by conducting experiments in a shock tube test rig by varying the factors like equivalence ratio, ignition temperature and ignition pressure. They reported that the ignition delay period for jojoba methyl ester was lower while the ignition temperature and ignition pressure were higher [47]. In the same year, Yusuf et al. [48] studied the in-cylinder pressure characteristics of a six-cylinder, direct injection, 306 kW diesel engine using esters of methyl tallowate as fuel. Peak rate of heat release for the blend of diesel methyl tallowate had found to be lower than diesel [48]. The combustion characteristics of waste cooking oil had compared by Yu et al. [49] with diesel as fuel in a direct injection diesel engine. Tashtoush et al. [50] investigated the combustion performance of ethyl esters of waste vegetable oil.

Nazar et al. [51] found that the duration of combustion is higher for straight vegetable oil when compared to methyl ester of vegetable oil. Sinha and Agarwal [52] investigated the combustion characteristics of rice bran oil in transport diesel engines. Combustion characteristics of sunflower oil had investigated by Usta et al. [53]. Lif and Holmberg [54] reported that combustion efficiency is improved when water is emulsified with diesel. Saikishan et al. [55] attempted to find the cetane number based on the properties of the biodiesel by using simulation techniques. In their work, they analyzed the influence of the various fuel properties namely density, viscosity, flash and fire points on the cetane number of a biodiesel and its various blends [55]. The kinetics of oxidation of rapeseed oil methyl ester (RME) had studied by Dagaut et al. [56] in a jet-stirred reactor for the first time. James et al. [57] had reported that biodiesel could alter the fuel injection and ignition processes whether neat or in blend form.

4. Emissions from biodiesel

Biodiesel mainly emits carbon monoxide, carbon dioxide, oxides of nitrogen, sulphur oxides and smoke. A brief review has made about these pollutants emitted from biodiesel.

Barsic and Humke [58] studied the effects of mixing peanut oil and sunflower oil with diesel fuel in a single cylinder engine. They observed that, with the increase of vegetable oil in the blend the amount of carbon deposits on the injector tip was increased when compared with 100% diesel fuel. They found that the vegetable oil fuel blends gave a lower mass-based heating value than that of diesel fuel [58]. Murayama et al. [59] reported that vegetable oils and methyl ester of rapeseed oil offered lower smoke and oxides of nitrogen (NO_X) emissions.

Exhaust emissions and durability characteristics using neat rapeseed oil as fuel was investigated by Hemmerlein et al. [60]. Scholl and Sorenson [61] reported that carbon monoxide, oxides of nitrogen (NO_X) and smoke emissions were slightly lower for soybean ester than diesel, whereas HC emission showed 50% reduction compared to diesel. Ali et al. [62] studied the use of different blends of methyl tallowate and ethanol with diesel as fuel in a Cummins 522 kW, six-cylinder, turbo-charged, direct injection. The tests showed that there was reduction in carbon monoxide emissions and no change in carbon dioxide and hydrocarbon emissions. The NO_X and smoke emissions were on par with diesel. The best performance and lower emissions were obtained for 80:13:7 (diesel:methyl tallowate:ethanol) blend [62]. Nwafor and Rice [63] reported that unburnt hydrocarbon emission was lower when operated with rapeseed methyl ester. A heavy-duty engine exhaust emission by using methyl ester soybean oil/diesel fuel blends was tested by Schumacher et al. [64].

Ladommatos et al. [65] investigated the effect of exhaust gas recirculation on diesel engine emissions. They noticed that a large reduction in NO_X emissions at the expense of higher particulate and unburnt hydrocarbon emissions [65]. The rapeseed oil methyl ester and diesel blend in a single cylinder diesel engine had tested by Desantes et al. [66]. They reported that when the inlet air temperature had increased from ambient, the carbon monoxide, NO_X and smoke emissions decreased considerably [66]. Yoshimoto et al. [67] investigated the emission characteristics of used frying oil along with 30% water emulsion in a single cylinder direct injection engine.

The use of methyl esters of sunflower oil, cottonseed oil, soybean oil and corn oil as fuel in a single cylinder direct injection diesel engine had been tested by Altin et al. [68]. Sidhu et al. [69] discussed the results of a laboratory investigations of particle formation from four different alternative diesel fuels, namely, compressed natural gas (CNG), dimethyl ether (DME), biodiesel, and diesel, under fuel-rich conditions in the temperature range of 800–1200 °C at pressures of approximately 24 atm. The effects of vegetable oil fuels and their methyl esters (raw sunflower oil, raw cottonseed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed oil) on a direct injected, four stroke, single cylinder diesel engine exhaust emissions was investigated by Altın et al. [70]. Niemi et al. [71] reported that the carbon monoxide emission was higher at all loads for different speeds with preheated mustard oil as fuel. The authors concluded that emissions decreased with preheating the oil [71]. In the same year, Bari et al. [72] discussed the effects of preheating of crude palm oil on emissions of diesel engine.

Senthil Kumar et al. [73] observed reduction in smoke, hydrocarbon and carbon monoxide emissions with the induction of hydrogen. However, the NO_X emissions increased due to higher combustion rates [73]. Kalligeros et al. [74] analyzed the emission characteristics on a stationary diesel engine fuelled with sunflower oil methyl ester/diesel blends. They also observed the decrease in particulate matter, carbon monoxide, hydrocarbon and nitrogen oxide emissions [74]. Dorado et al. [75] tested the use of methyl ester of used olive oil as fuel in a direct injection diesel engine. They reported that carbon monoxide, carbon dioxide, oxides of nitrogen and sulphur dioxide emissions decreased by 59%, 8.6%, 32% and 57% respectively and that the smoke emission was low. They concluded that the methyl ester of olive oil could be used as fuel [75]. Raheman and Phadatare [76] tested karanja methyl ester and its blends with diesel from 20% to 80% by volume in a single cylinder direct injection diesel engine and they found that the carbon monoxide, smoke and NO_X emissions were lower. The chemical and toxicological characteristics of emissions from an urban bus engine fuelled with diesel and biodiesel blend were studied by Turrio-Baldassarri et al. [77]. The authors also evaluated the effect of the fuels under study on the size distribution of particulate matter (PM) [77]. Tsolakis and Megaritis [78] studied

the exhaust gas assisted reforming of rapeseed methyl ester for reduced exhaust emissions of compression ignition engines. The production of hydrogen-rich gas by catalytic exhaust gas assisted fuel reforming of rapeseed methyl ester had investigated experimentally as a way to provide the required hydrogen for the reduction of biodiesel emissions [78].

Suryawanshi and Deshpande [79] studied the effect of exhaust gas recirculation and retardation injection timing on diesel engine fuelled with pongamia methyl ester. They reported that oxides of nitrogen emissions were lower with injection timing retardation and exhaust gas recirculation compared to standard conditions [79]. Sukumar Puhan et al. [80] studied the emission characteristics of mahua oil methyl ester as biodiesel. Usta [81] conducted an experimental study on exhaust emissions of a diesel engine fuelled with tobacco seed oil methyl ester. The results showed that the addition of tobacco seed oil methyl ester to the diesel fuel reduced CO and SO_2 emissions while causing slightly higher NO_X emissions [81]. The emission characteristics of a diesel engine fuelled with methyl esters of rubber seed oil was evaluated by Ramadhas et al. [82].

Labeckas and Slavinskas et al. [83] analyzed the emission characteristics of four stroke, four-cylinder, direct injection, unmodified, naturally aspirated diesel engine when operating on neat rapeseed methyl ester (RPE) and its 5%, 10%, 20% and 35% blends with diesel fuel. They found that carbon monoxide, hydrocarbon and visible emissions had decreased while an oxide of nitrogen emissions increased for methyl ester compared to diesel [83]. Narayana Reddy and Ramesh [84] studied the effect of injection timing, injector-opening pressure, injection rate and air swirl level on the performance of jatropha oil fuelled diesel engine. The authors concluded that advancing the injection timing and increasing the injector-opening pressure reduce hydrocarbon and smoke emissions significantly [84]. Shi et al. [85] described the emission characteristics of an oxygenated diesel fuel blend on a diesel engine.

Lin et al. [86] investigated the emissions of polycyclic aromatic hydrocarbons (PAHs), carcinogenic potencies (BaP_{eq}) and particulate matter, fuel consumption and energy efficiency from the generator under steady state for seven test fuels: P0 (Premium Diesel Fuel), P10 (10% palm-biodiesel +90% P0), P20, P30, P50, P75 and P100. Reyes and Sepúlveda [87] investigated the emission characteristic with neat diesel fuel and ester of salmon oil. The control of oxides of nitrogen emission of biodiesel (rapeseed oil, linseed oil, rice bran oil, soybean oil) was investigated by Agarwal et al. [88]. Sendzikiene et al. [89] investigated the inter solubility of mixtures of rapeseed oil methyl esters, diesel fuel and ethanol. They evaluated emissions of exhaust gases of these stable fuel mixtures [89]. Armas et al. [90] focused on the measurement and analysis of the smoke opacity resulting from a diesel engine fuelled with conventional fuel and bio-fuel under transient conditions. Methyl esters obtained from used cooking and unused vegetable oils had tested [90]. The use of hot exhaust gas recirculation for oxides of nitrogen control in a compression ignition engine fuelled with biodiesel from Jatropha oil was studied by Pradeep and Sharma [91]. Lin and Lin [92] discussed the emission characteristics of a three-phase emulsion of biodiesel from soybean produced by peroxidation. Sahoo et al. [93] reported that Polanga oil methyl ester showed lesser exhaust emission as compared to high-speed diesel. Kwanchareon et al. [94] studied the solubility of a diesel–biodiesel–ethanol blend, and its emission characteristics from diesel engine. Melissa A Hess et al. [95] investigated two routes to reformulate soy-based biodiesel in an effort to reduce nitrogen oxide emissions.

A new theory had proposed by Ban-Weiss et al. [96] for numerical investigation of emission characteristics of biodiesel. Lin et al. [97] compared the trace formation from the exhaust gas of a diesel engine when operated using the different fuel types of fuel such as neat biodiesel (waste cooking oil), biodiesel/diesel blends, and normal diesel fuels. Tsolakis et al. [98] studied the emission characteristics of a diesel engine operating on rapeseed methyl ester blends with exhaust gas recirculation. The influence of biodiesel from rapeseed oil on the injection, spray, and engine characteristics with the aim to reduce harmful emissions was discussed by Kegl [99].

5. Performance of biodiesel

The performance parameters such as power output, specific fuel consumption, brake thermal efficiency of different biodiesels had been reviewed.

Yarbrough et al. [100] studied the performance of a diesel engine with six variants of sunflower oil as fuel. They reported that refined sunflower oil gives satisfactory results and found that degummed and dewaxed vegetable oil prevents engine failure. They also concluded that raw sunflower oil cannot be a fuel but modified sunflower oil can be used as a fuel for diesel engines [100]. The use of sunflower, safflower and rapeseed oils as liquid fuels was investigated by Bettis et al. [101]. They found that engine power output to be equivalent to that of diesel fuel, but long-term durability tests indicated severe problems due to carbonization [101]. Strayer et al. [102] investigated the feasibility of using degummed canola oil and high erucic rapeseed oil as diesel fuel substitutes in small and large diesel engines.

They reported that specific fuel consumption and particulate matter with these oils were higher and concluded that the engine performance is better with degummed canola oil when compared with crude canola oil for 25 h of operation [102]. Pryor et al. [103] conducted short and long-term engine tests using neat soybean oil in a small diesel engine. Short-term tests with soybean oil indicated the performance similar to that of diesel and long-term testing could not be carried out due to power loss and carbon build-up on the injectors. They concluded that the soybean oil can be considered for short-term operation only [103]. Ryan et al. [104] investigated the injection and combustion properties of several vegetable oils namely peanut oil, cottonseed oil, sunflower oil and soybean oil.

Performance characteristics, emission characteristics and heat release of biodiesel had investigated by Laforgia and Ardito [105]. The use of rapeseed oil blends as fuel in an air-cooled, 300 cm^3 indirect injection diesel engine was studied by Nwafor and Rice [106]. It has observed that the power output was less for neat rapeseed oil and increased with increasing proportion of rapeseed oil in the blend [106]. Sapaun et al. [107] reported that the power output for palm oil and diesel blend was similar to that of diesel. Short-term tests using palm oil showed no signs of adverse combustion chamber wear or increase in carbon deposits or contamination of lubricating oil [107]. Radu and Mircea [108] investigated sunflower oil/diesel blend in a three cylinder, 33 kW DI diesel engine. The vegetable oil/diesel blend has found to be better for power development with modified injection timing [108]. Niemi et al. [109] tested a turbo-charged four-cylinder direct injection diesel engine using mustard oil. Their tests showed that the engine developed power equal to that of diesel. However, they concluded that long-term tests should be carried out [109].

Mc Donnel et al. [110] investigated the use of semi-refined rapeseed oil as a diesel fuel extender. They reported that the engine performance was better for 25/75 rapeseed oil/diesel blend. The use of rapeseed oils has found to shorten the injector life due to carbon build up, even though there was no wear on engine components or lubricating oil contamination [110]. Al-Widyan

et al. [111] studied the use of ethyl ester of waste vegetable oil and diesel blends in proportions of 75/25, 50/50, 25/75 as fuel in a naturally aspirated direct injection diesel engine tested at different speeds. The fuel economy was observed to be better. They concluded that 75/25 blend of the esters of waste cooking oil and diesel gives the best performance [111].

Bari et al. [112] presented results of performance and durability tests of a diesel engine fuelled with crude palm oil. They observed heavy carbon deposits in the combustion chamber, wear of piston rings, and plunger and delivery valve of injection pump, uneven spray formation, scuffling of the cylinder lining, when the engine has made to run with crude palm oil [112]. The performance of diesel engine fuelled with jatropha oil and its diesel blends had investigated by Pramanik [113]. Significant improvement in engine performance was observed when compared to neat vegetable oil. The specific fuel consumption was reduced due to decrease in the viscosity of the vegetable oil. Acceptable thermal efficiencies of the engine had obtained with blends containing up to 50% of jatropha oil [113]. The blends of rubber seed oil/Ramadhas et al. [114] investigated diesel in proportion of 20/80, 40/60, 60/40, 80/20 in a 5.5 kW single cylinder direct injection diesel engine. They reported that blends up to 80/20 showed acceptable thermal efficiency and specific fuel consumption but the blends developed heavy carbon deposits [114].

The performance, emission and combustion parameters of a single cylinder diesel engine running on biodiesel from rubber seed oil and its blends with diesel was presented by Pradeep and Sharma [115]. Brake thermal efficiencies were found lower for biodiesel blends compared to diesel. Higher combustion duration and lower heat release rates was recorded for biodiesel [115]. Pugazhvadivu and Jeyachandran [116] tested a single cylinder direct injection diesel engine with waste frying oil as fuel. They found that the fuel consumption was marginally higher than diesel [116]. The performance of used cooking oil in a 4 stroke, 4 cylinders and 75 kW diesel engine had tested by Cetinkaya et al. [117].

The potentialities of biodiesel as an alternative fuel based on strategic considerations and field experiences in boilers and diesel engines were investigated by Carraretto et al. [118]. The various blends of rubber seed oil and diesel were prepared and its important properties such as viscosity, calorific value, flash point, fire point, etc. had evaluated and compared with that of diesel by Ramadhas et al. [119]. Long run tests were conducted using optimized blend and diesel. They recommended that rubber seed oil–diesel blend fuel is more suitable for rural power generation [119]. The engine performance by using used cooking oil had investigated by Çetinkaya et al. [120]. Kinney and Clemente [121] modified the soybean oil to enhance the performance of diesel engine. Performance and emission characteristics of mahua oil (madhuca indica oil) ethyl ester in a four stroke natural aspirated direct injection diesel engine was carried out by Puhan et al. [122]. The spray characteristics, engine performance, emissions, and combustion characteristics of water emulsions of the blended fuel with equal proportions of rapeseed oil and diesel was analyzed by Yoshimoto [123].

Lin et al. [86] investigated the emissions of polycyclic aromatic hydrocarbons and particulate matter, fuel consumption and energy efficiency from the diesel engine under steady state for different blends of palm oil biodiesel and diesel. The authors reported that the brake specific fuel consumption increased with rising palm-biodiesel blends due to the low gross heat value of palm-biodiesel [86]. Lin and Lin [124] carried out the performance characteristic of biodiesel produced by the peroxidation process. Labeckas and Slavinskas [125] presented the comparative bench testing results of a four stroke, four-cylinder, direct injection, unmodified, naturally aspirated diesel engine when operating on neat rapeseed methyl ester and its 5%, 10%, 20% and 35% blends with diesel fuel. They examined the effects of rapeseed methyl ester inclusion in diesel fuel on the brake specific fuel consumption of a high-speed diesel engine [125]. Altıparmak et al. [126] tested the performance characteristics of tall oil methyl ester–diesel fuel blends. Murillo et al. [127] studied the engine performance and emission results of biodiesel derived from used cooking oil when applied in different proportions in outboard engines. An experimental investigation concerning the electric energy generation using blends of diesel and soybean biodiesel had been presented by Pereira et al. [128]. The results show that for all the mixtures tested, the electric energy generation had assured without problems [128]. The performance of biodiesel obtained from mahua oil and its blend with high-speed diesel in a Ricardo E6 engine has been presented by Raheman and Ghadge [129].

6. Conclusions

Even though 350 oil-bearing crops are identified, only few are potential biodiesel like sunflower, rapeseed, palm and jatropha. It is observed that biodiesel has similar combustion characteristics as diesel and also found that the base catalyst performs better than acid catalyst and enzymes. It is also inferred that the engine performance was inferior when using vegetable oil/ diesel blend as the high viscous oil caused injector coking and contaminated the lubricating oil. The tests with refined oil blends indicated considerable improvement in performance. The emission of unburnt hydrocarbon from the engine was found to be more on the all the fuel blends as compared to diesel. The emission of oxides of nitrogen from the engine found to be higher on the all fuel blends as compared to diesel.

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